



# Air Force Research Laboratory

## Materials & Manufacturing Directorate

Wright-Patterson Air Force Base • Dayton, Ohio

Fall 2003

### Advances in Net-Shape Powder Metallurgy and Protective Coating Processes Lower Propulsion System Production Cost

The Air Force Research Laboratory's Materials and Manufacturing Directorate, working with industry, has made significant advancements in the development of new fabrication methods and protective coating processes for high-performance, low-cost, net-shape powder metallurgy (PM) components for aircraft and rocket engines.

Net-shape PM has intrigued researchers and industry for more than 40 years because it eliminates complex machining operations, thereby reducing costs. Working with Boeing Rocketdyne and LNT USA, the directorate's Metals, Ceramics and Nondestructive Evaluation Division is developing rotating pump

component materials and processes for turbine engines that can trim parts weight by 35 percent, reduce production costs by 45 percent, and lower the projected costs of fabricating a net-shape PM manufactured bladed disk or "blisk" by more than 40 percent.

Successful development of PM blisk fabrication methods incorporating high-strength, environmentally-compatible superalloys enables revolutionary advances in turbopump rotating element materials and designs. New materials and fabrication methods enable the aerospace industry to manufacture cryogenic-compatible turbine blisks combining the highest performing nickel-base superalloy turbine materials, normally reserved for airbreathing gas turbine engines, with the high reliability and low maintenance of the typical low strength superalloys.

Turbine rotors used to propel jet aircraft and rockets are fabricated from forged disks with mechanically attached cast blades, or are machined from one-piece forgings. The state-of-the-art method for manufacturing the disks is to build them from either conventional high-strength, nickel-base superalloys and coat them for environmental protection or manufacture them from moderate strength alloys fully compatible in the applicable environment.

Coatings introduce reliability and cost issues, while the moderate strength alloys sacrifice performance. Net-shape PM is a method for "casting" with solid metal powder and consolidating to a net shape, which combines inherent design and processing benefits with the

performance benefits of forgings to produce parts with structure and properties comparable to forgings.

Boeing Rocketdyne, supported by the directorate and LNT USA, has developed a technology for fabricating a high-strength blisk made via selective net shape (SNS) PM processing with an environmentally compatible hot isostatic pressing (HIP)-bonded surface layer (HBSL). The SNS PM process uses a precision-machined, low carbon steel mold, analogous to an investment-casting mold. The part details are machined into a mold, which is then assembled, welded into a capsule, and then filled with metal powder, evacuated, and hot isostatically pressed (HIP'd) to compact the powder. Conventional machining and chemical milling is used to remove the carbon steel tooling.

The new approach offers a revolutionary opportunity to protect very high performance alloys in turbine environments, which are normally hostile to these alloys. These environments are most commonly hydrogen- or oxygen-rich gases, which respectively embrittle or burn state-of-the-art, high-strength superalloys. The underlying concept is to deposit a layer of an alloy, selected for its environmental resistance and compatibility with the core alloy, on the machined surface of the soft tooling (low carbon iron) employing a method such as vacuum plasma spray. After tool assembly, powder filling, degassing, sealing and HIP, the core superalloy powder has consolidated and HIP-bonded to the outer surface of the environmental alloy on the sacrificial tooling. This durable and damage-tolerant HBSL provides environmental compatibility and improves the as-

(continued on page 3)



*Prototype blisk fabricated using the net-shape powder metallurgy-hot isostatic pressing method.*

# Laser Hardened Materials Evaluation Laboratory Simulates Space Environment for Advanced Materials and Space Systems Testing

A cooperative effort between the Air Force Research Laboratory Materials and Manufacturing Directorate (ML) and the Air Force Space Battlelab recently resulted in an upgrade of the Laser Hardened Materials Evaluation Laboratory (LHMEL), a world-class material characterization facility. Because of these efforts, the capability of the facility has been expanded beyond laser effects testing to include large-scale thermal testing and environment simulation.

The collaboration between the ML Hardened Materials Branch and the Space Battlelab provided the Department of Defense (DoD) the capability to test articles in a simulated space environment prior to launch and activation. The savings are enormous.

The joint venture enabled LHMEL to activate a highly capable, 27-foot tall, 20-foot diameter, cryogenically-shrouded vacuum chamber. The speed at which the chamber “pumps-down,” and the addition of a cryogenic and vacuum compatible turntable, which can be used to mount and rotate samples in the chamber without breaking vacuum, allows multiple experiments to be conducted daily. These research capabilities, which can be used to simulate the high-vacuum, cryogenic temperature, and solar radiation effects of the space environment on materials and systems, are valued at over \$25 million.

Originally built by the Propulsion Laboratory, now the Air Force Research Laboratory Propulsion Directorate, in the early 1960s, the vacuum chamber was originally used for space materials and systems qualification work. When the Space Battlelab, which operates under the direction of the Air Force Space Command, required a large-scale vacuum for testing a satellite, engineers at LHMEL began making the modifications required to make the chamber operational after years of sitting idle. The Materials and Manufacturing Directorate Hardened Materials Branch, which oversees LHMEL operations, and the Space Battlelab shared the cost of the modifications.

The Laser Hardened Materials Evaluation Laboratory, a one-stop infrared testing resource, provides the Air Force with basic

material response data, optical material characterization, hardening concept validation, and thermal simulation capabilities using a unique collection of laser wavelengths, power levels and operating modes. LHMEL supports the ML mission to provide laser protection materials and hardening expertise for DoD personnel and systems.

In 2002, after the chamber became operational, scientists and engineers at LHMEL began seven weeks of thermal and

“pumps-down” using a series of vacuum pumps and its cryoshroud (an internal liner inside the chamber that is filled with liquid nitrogen) from ambient pressure (760 torr) to  $10^{-6}$  torr in an hour and a half. In addition to aiding the “pump-down” process, the cryoshroud also simulates the cold temperature of space, reaching temperatures as low as 77 degrees Kelvin.

The chamber is equipped with a OneSun solar simulator and a cryogenic and high-vacuum compatible turntable, which can be used to mount and rotate samples 360 degrees in the chamber. Scientists can monitor samples or systems with diagnostics equipment such as thermocouples, strain gauges, or infrared detectors using over 30 vacuum feed-throughs from the chamber to data collection equipment outside of the chamber.

In addition, the chamber is situated to permit its use in conjunction with 150 kW of continuous wave output power from the nation’s largest CO<sub>2</sub> laser, LHMEL II. LHMEL II is often used to validate material response models before advances to higher-cost, full-scale validation tests at other facilities. Interacting with the chamber, scientists can use the laser to focus a low energy level, which can simulate temperatures equivalent to that of the sun on a six-foot diameter area.

The LHMEL facility has two additional vacuum chambers. Measuring seven feet in diameter by nine feet in length, the second chamber has been involved in a number of National Aeronautics and Space Administration-sponsored programs. The

smallest chamber, measuring 30 inches in diameter by 30 inches in length, is portable and is used for materials phenomenology experiments at the basic material level.

The Laser Hardened Materials Evaluation Laboratory offers nationally unique material testing and laser processing opportunities to accommodate a wide variety of testing. Operated by Anteon Corporation, LHMEL (continued on page 3)



*An outside view of the Laser Hardened Materials Evaluation Laboratory's highly capable, 27-foot tall, 20-foot diameter, cryogenically-shrouded vacuum chamber.*

environmental testing of a space-qualified, fully functioning, operational micro-satellite. Tests simulated conditions that the satellite would encounter during its lifetime, including regular solar cycles representing excursions into day and night. A simulated ground station collected telemetry data and received signals produced by the satellite during testing.

The largest of three vacuum chambers currently available at LHMEL, the new chamber



(continued from Page 2)

supports laser and space simulation testing for almost any user on a reimbursable basis, whether that user is a DoD organization, a government-sponsored contractor, or an industry-funded entity. In recent years, facility use has nearly doubled, increasing income and allowing the Air Force to maintain the multi-million dollar facility at a fraction of the annual operating cost and at a reduced economic burden to the Air Force.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at [techinfo@afrl.af.mil](mailto:techinfo@afrl.af.mil) or (937) 255-6469. Refer to item 03-084.



**VISIT US AT  
WWW.AFRL.AF.MIL**

(continued from Page 1)

processed surface finish, which enhances nondestructive testing probability of detection.

This effort directly supports the Air Force Research Laboratory's Integrated High Payoff Rocket Propulsion Technology (IHPRPT) program, designed to provide technologies enabling higher performing, lower-weight, and lower-cost advanced propulsion systems. The gaseous oxygen-rich turbine provides the opportunity for early insertion of high-payoff PM blisk technology into current and proposed engines, with extension and additional payoff to hydrogen-rich and elevated temperature turbines.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at [techinfo@afrl.af.mil](mailto:techinfo@afrl.af.mil) or (937) 255-6469. Refer to item 03-224.

## Composite Patch Vacuum-Mold Repair System Transferred To Commercial Industry

A revolutionary composite patch repair system developed at the Air Force Research Laboratory to reduce the amount of time required to complete metal aircraft structure repairs at field locations has been transferred to commercial industry.

Developed at the Air Vehicles Directorate, the new "Vacuum-Mold Repair System" (VMRS) has been refined by the Materials and Manufacturing Directorate's System Support Division (Materials Integrity Branch) and has demonstrated promising results during extensive testing. Built by Lockheed-Martin Corporation, the VMRS incorporates a quick, reusable mold that replicates the contour of a damaged part in minutes, versus hours using conventional splash-mold techniques. Airtech Advanced Materials Group has obtained a license to produce and sell this new technology, which they have entitled the Impression Master®.

Vacuum-mold repair technology offers a number of advantages over conventional splash-mold methods, including low lifecycle costs, since the mold bag used to complete the patch repairs is reusable, and significant reductions in weight because each bag weighs only 30 pounds. VMRS technology is environmentally friendly, since neither potentially harmful chemicals nor temperatures are used to replicate the damaged structure.

Prior to the development of vacuum-mold repair, the most effective way of repairing metal aircraft structures depleted from excessive wear and fatigue or damaged in combat was to fly the aircraft to a maintenance depot or complete the repairs at a field location using conventional splash-mold techniques. Splash-mold techniques using plastic or ceramic curing compounds are effective in repairing multiple contour structures; however, they're also costly and time-consuming, since they require one-time use molds. Splash-mold techniques necessarily require that large quantities of repair materials be readily available to ensure several repairs can be completed. They also necessitate unacceptably long "downtime" of an equivalent undamaged aircraft, while the mold is curing.

Another disadvantage of splash-mold techniques is that the composite material handling and processing methods employed require cold storage of materials using "clean room" equipment that is bulky, heavy and expensive, and requires extensive training

and experience. A major concern in metal aircraft structure repair is transport of aircraft to maintenance depots, which can be very expensive and often creates logistics problems, since the repairs have to be worked in around periodic maintenance already scheduled or in progress.

Engineers at the Air Force Research Laboratory (AFRL) Materials and Manufacturing Directorate, working with the Air Vehicles Directorate (known at that time as the Flight Dynamics Laboratory) and Lockheed-Martin Corporation, successfully refined and tested VMRS at six military installations, including a U.S. Navy



*Vacuum-Mold Repair System*

maintenance depot in San Diego, Calif. The test program revealed outstanding results and eventually led to the successful technology transfer of VMRS to Airtech Advanced Materials Group, a leading manufacturer of vacuum bagging and composite tooling materials. Airtech products are used in the aircraft, aerospace, wind power generation, automotive, auto racing, marine craft, recreational, architectural, medical, packaging and printed circuit board industries, several of which could benefit from the refined VMRS technology.

The VMRS process uses a quick, reusable mold for transferring the contour of an equivalent undamaged metal structure and laying up of a graphite-epoxy composite patch. The new system also incorporates an integral heating device and other equipment, that when packaged together, provide a complete

(continued on page 4)

(continued from Page 3)

composite repair kit. VMRS can replicate the contour of a damaged aircraft part in less than 10 minutes versus several hours required by current splash molds, which are not reusable. As a result, technicians are able to complete their repairs and return the aircraft to flying status much faster.

VMRS employs a mechanically hardened tooling technique that uses a sealed rubber bag containing lightweight granular filler. Once positioned over the damage location of an equivalent aircraft, a vacuum is drawn within the bag, which causes the rubber skin to constrict on the filler, locking it in a firm arrangement and replicating the surface geometry of the damage location. This process allows composite patch repairs to be completed quickly in the field. Another primary advantage of VMRS is the equivalent undamaged aircraft is needed only for a short time and is then free to contribute to the ongoing conflict or another mission. Since VMRS procedures are relatively simple, system training is straightforward.

For more information, contact the Materials and Manufacturing Directorate's Technology Information Center at [techinfo@afrl.af.mil](mailto:techinfo@afrl.af.mil) or (937) 255-6469. Refer to item 02-164.

## NEW START CONTRACTS

- Thermal Sprayed Polymeric Coatings For Landing Gear — F33615-03-M-5016
- Quasicrystalline Thin Films For Corrosion Inhibition — F33615-03-M-5017
- Nano-Engineered Coatings Based On Functionalized — F33615-03-M-5018
- Conductive Repair Coatings — F33615-03-M-5019
- Quick Curing Conductive Repair Coating For Electrostatic Discharge Applications — F33615-03-M-5020
- Advanced Carbon-Based Fan Duct Heat Exchanger — F33615-03-M-5021
- Enhanced Strength Aerospace Carbon Foam Heat Exchanger — F33615-03-M-5022
- Gas Turbine Engine Oil Additives For Advanced Bearings — F33615-03-M-5023
- Gas Turbine Engine Oil Additives For Advanced Bearings II — F33615-03-M-5024
- Novel Flame And Impact Resistant Foam Core I — F33615-03-M-5025
- Novel Flame And Impact Resistant Foam Core — F33615-03-M-5026
- Innovative Durable Thermal Protection Systems — F33615-03-M-5027
- Optimized Hybrid Leading Edge For Reusable Launch Vehicles — F33615-03-M-5028
- Advanced Surface Heat Exchanger Via High Strength Graphite Foam — F33615-03-M-5030
- Durable Hybrid Thermal Protection System — F33615-03-M-5031
- Lightweight Foamed Composites With Superior Flame/Impact — F33615-03-M-5033
- Conformal Applique Thermal Control In Space — F33615-03-C-5034
- Materials And Manufacturing Directorate Thrust (MMDT) — F33615-03-2-5035
- Lightweight Carbon Ceramic Composites For Thermally — F33615-03-M-5036
- Lightweight Low Contamination Laser Beam Dump — F33615-03-M-5038
- Structural Improvement Of High Thermal Conductivity Carbon — F33615-03-M-5039

The USAF Materials Technology Highlights is published quarterly to provide information on materials research and development activities by Air Force Research Laboratory's Materials & Manufacturing Directorate. For more information on subjects covered in "Highlights" or to be added to the "Highlights" mailing list, contact the Materials & Manufacturing Directorate Technology Information Center at (937) 255-6469 or e-mail at [techinfo@afrl.af.mil](mailto:techinfo@afrl.af.mil). Approved for Public Release (ASC/PA#03-2354).

AFRL/MLOP-TIC BLDG. 653  
2977 P STREET, SUITE 13  
WRIGHT-PATTERSON AFB OH 45433-7746

OFFICIAL BUSINESS



Air Force  
Research Laboratory  
AFRL